Energy and Environmental Gains of Warm and Half-Warm Asphalt Mix: Quantitative Approach

87th Annual TRB Meeting

January 16, 2008

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McCONNAUGHAY TECHNOLOGIES

A Suit-Kote Company

Acknowledgements

Professor Yves Le Goff – LEACO consultant

Yves Martineau – LEACO consultant

Alain Romier – Fairco

Bernard Heritier – Eiffage Travaux Publics

Andre Loustau - LEACO

Pavement engineering is the art of molding materials that we do not wholly understand into shapes we cannot precisely analyze so as to withstand forces we cannot assess in such a way that the community at large has no reason to suspect our ignorance.

Introduction

- 100+ years of HMA – premier material for roadway construction
- Heating and complete drying of all aggregates
- Mix with molten asphalt

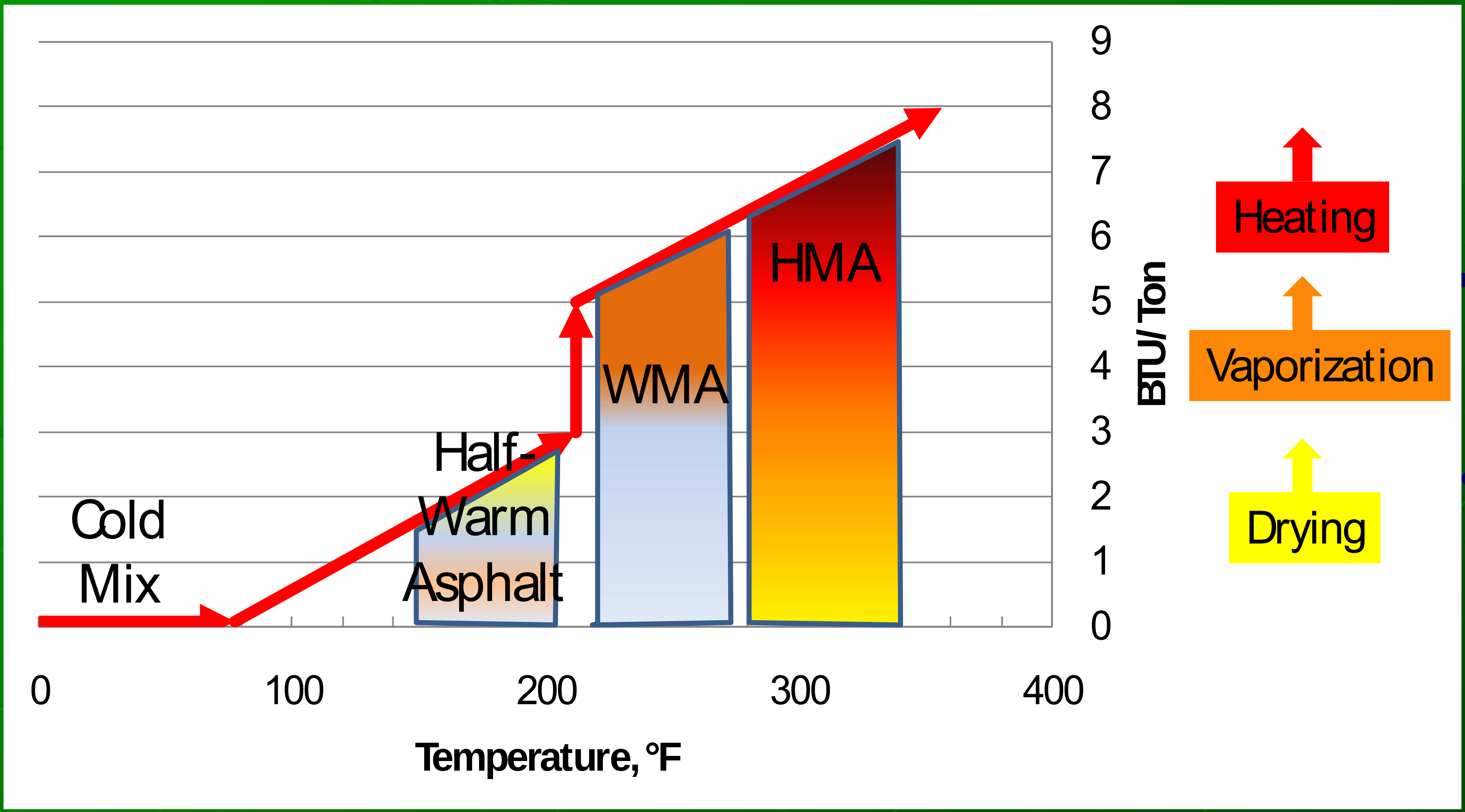
Introduction

- However, for many years, industry has been looking for ways to reduce the amount of energy required to produce HMA
- Combining energy savings with environmental benefits

Many Solutions

- Warm Mix
  - Organic Additives (Sasobit, Cecabase RT 945, others)
  - Foaming – with or without additives (Aspha-min, Advera, Evotherm, WAM Foam, Double Barrel Green)
- Half Warm Mix
  - Foaming (LEA, Evotherm)

Mix Types



9
8
7
6
5
4
3
2
1
0
BTU/Ton
Heating
Vaporization
Drying
HMA
WMA
Half-
Warm
Asphalt
Cold
Mix
0
100
200
300
400
Temperature, °F

Mixtures Included

Number	Type	Method
Nº1	HMA Ref.	Standard
Nº2	Warm Mix	Organic Additive
Nº3	Warm Mix	Double Coat Foam
Nº4	Half-Warm Mix	Emulsion coating
Nº5	Half-Warm Mix	Foam – PHS
Nº6	Half-Warm Mix	Foam - CS

Energy Equation – No Change of State

$$\Delta H = M * c_p (T_f - T_i)$$

where:

- M = mass in kg
- c_p = specific heat in J/(kg*°C)
- T_i = initial temperature (°C)
- T_f = final temperature (°C)

Energy Equation – Physical Change of State

$$\Delta H = L_v (M_{vf} - M_{vi})$$

where:

- L_v = latent heat of vaporization in J/kg
  - M_{vi} = initial mass of vapor in kg
  - M_{vf} = final mass of vapor in kg

Thermal Properties

C_{agg} – specific heat of aggregate = 0.837 kJ/kg/°C
$C_{bitumen}$ – specific heat of bitumen = 2.093 kJ/kg/°C
C_{water} – specific heat of water = 4.185 kJ/kg/°C
L_v – latent heat of vaporization = 2256 kJ/kg
C_{vap} – specific heat of water vapor = 1.830 kJ/kg/°C

Thus, the vaporization of 10 kg of water requires 22.5 MJ, as much energy as required to heat 154 kg of coarse aggregate from 22°C to 197°C.

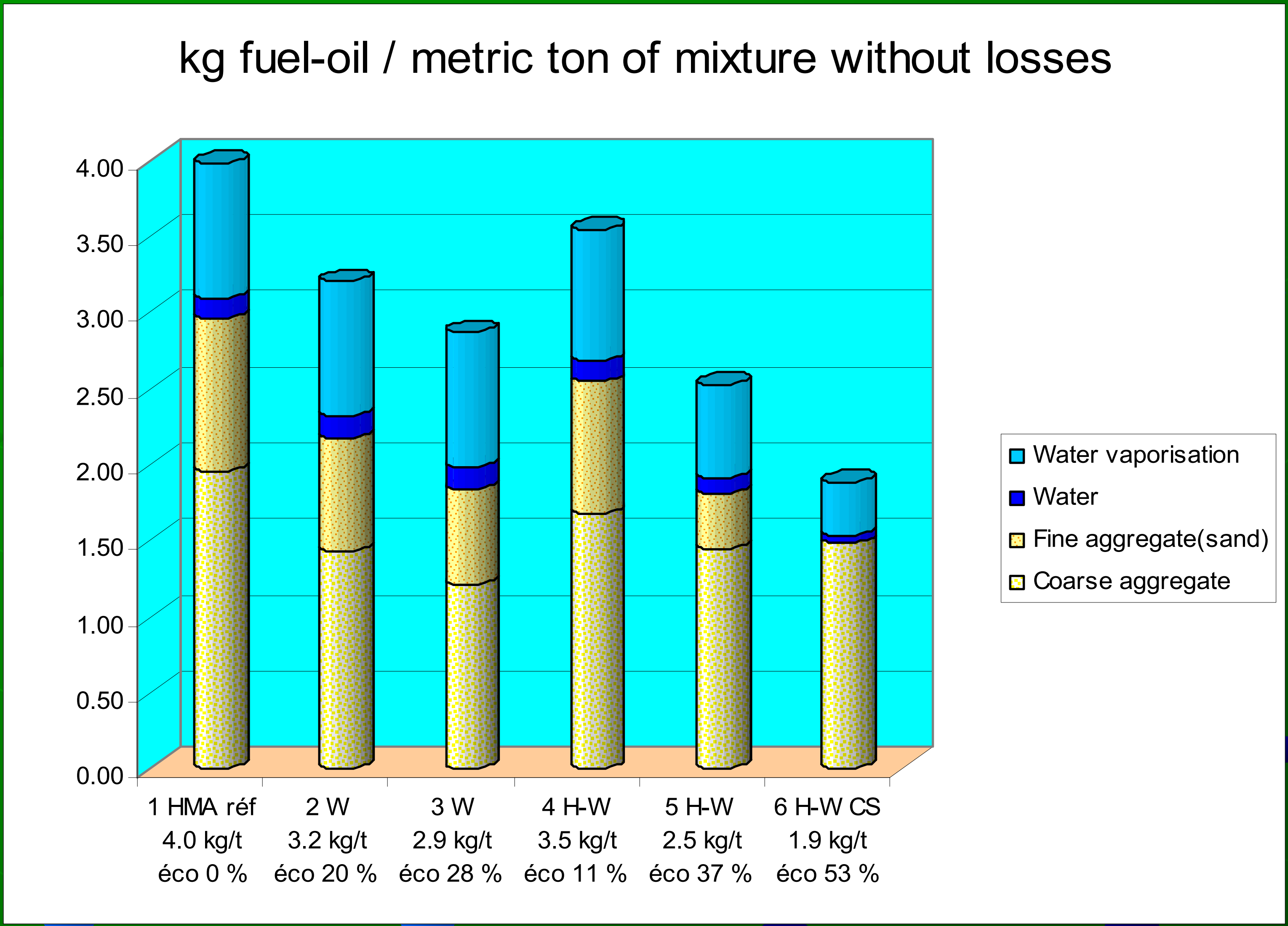
Common Conditions

Table 1 : Conditions common to the six processes		
cp of coarse aggregate	837	J/kg.K
cp of fine aggregate (sand)	837	J/kg.K
cp of asphalt binder	2093	J/kg.K
cp of water	4185	J/kg.K
Net heating value of fuel oil	40.4	MJ/kg
Percentage of coarse aggregate	66	%
Water content of coarse aggregate	1	%
Water content of fine aggregate (sand)	3	%
Initial T° of sand and water	15	°C

Different Conditions

Table 2 :Conditions differentiating the six processes					
		% sand in dryer	Additional water in % of batch mass	Residual water in % of batch mass	Final T of mix in °C
N°1	HMA ref	100	0	0	165
N°2	Warm, Bitumen +wax or foam additive	100	0	0	130
N°3	Warm, Double coating	100	0	0	115
N°4	Half-Warm, Emulsion coating	100	2	0.7	90
N°5	Half-Warm, Foam coating	50	1	0.7	90
N°6	Half-Warm, Sequential coating	0	0	0.7 *	90
* Water content obtained during testing of half warm mix, sand not heated(N°6)					

Energy Consumption

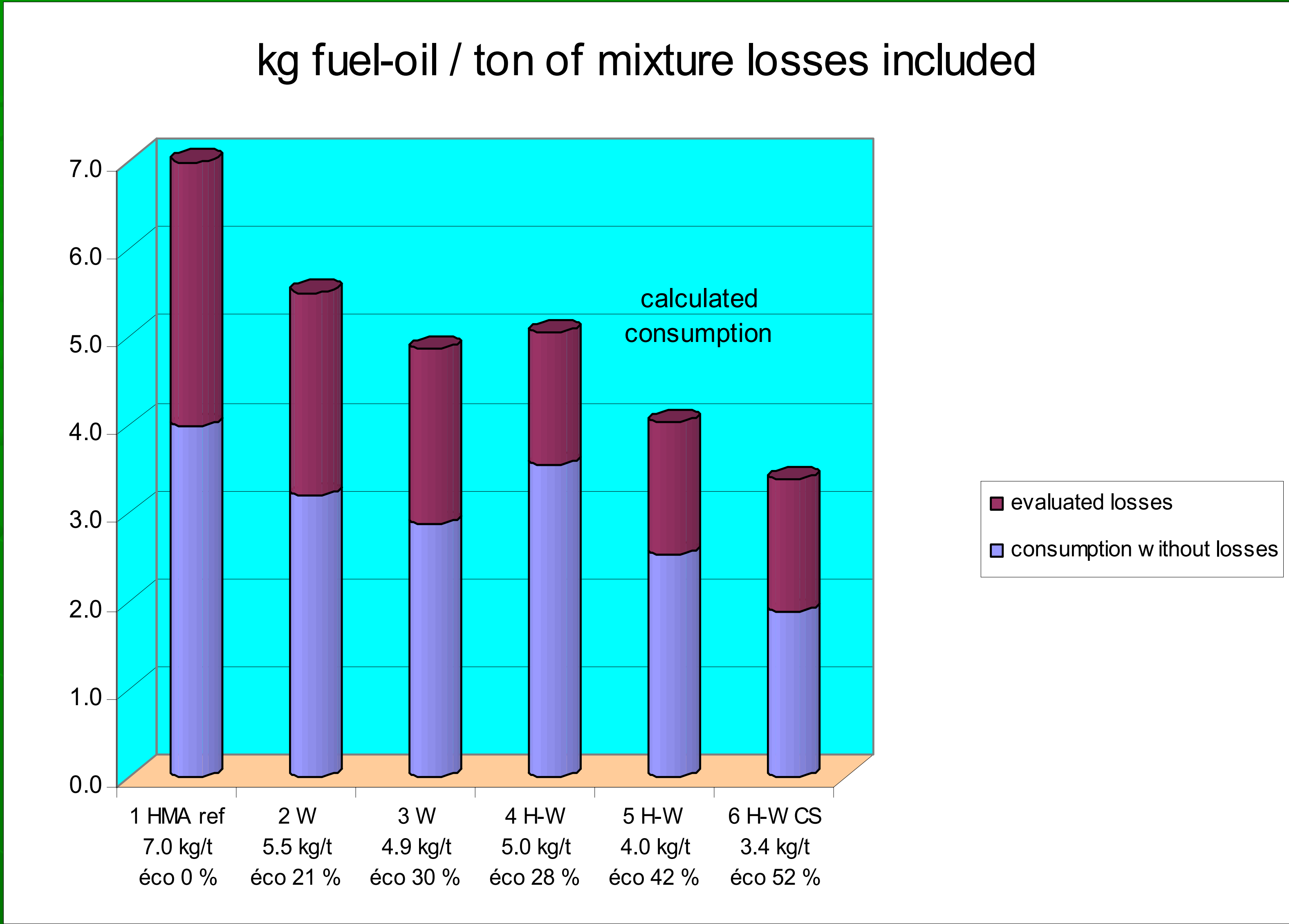


Influence of Heat Losses During Mixing

- Measured (HMA) energy consumption attributable to losses were 3 kg of fuel oil per metric ton of mix
- Proportionality rule used for others
  - Based on difference between process temperature and ambient temperature
  - A mix produced at 165°C with an ambient temperature of 15°C has heat losses which are twice those for mixes produced at 90C

$$(165-15)/(90-15) = 2$$

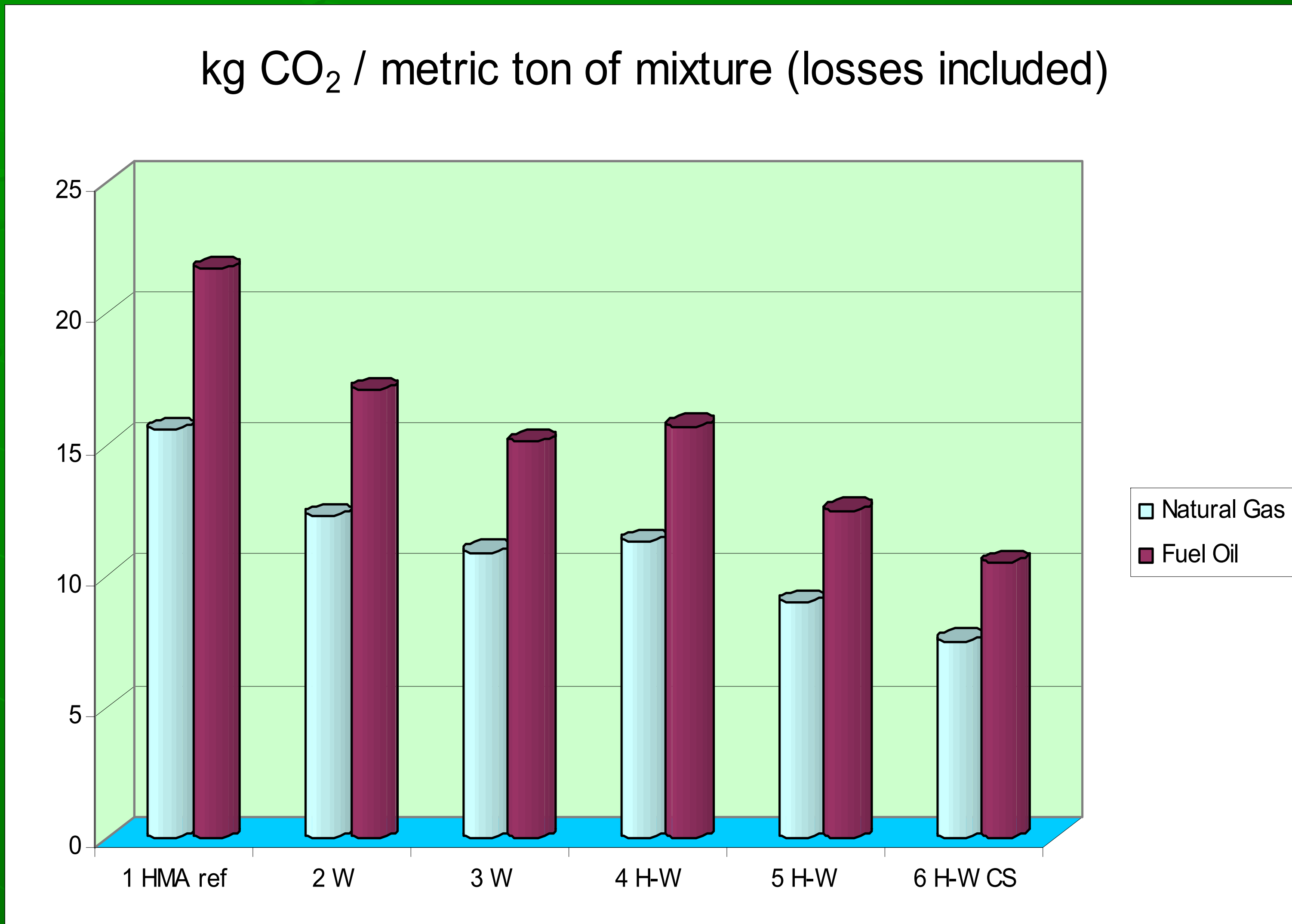
Energy Consumption



Emissions By Fuel Type

TABLE 3 Influence of type of fuel on consumed energy and GGEs		
	NHV MJ/kg	Mass of CO_2 emission / mass of fuel
Fuel oil	40.4	3.11
natural gas	49.8	2.75

CO_2 Emissions



Energy Management

- No problem with HMA and warm mixes
- More complex with half-warm mixes
  - Unstable kinetic systems with constantly evolving energy contents

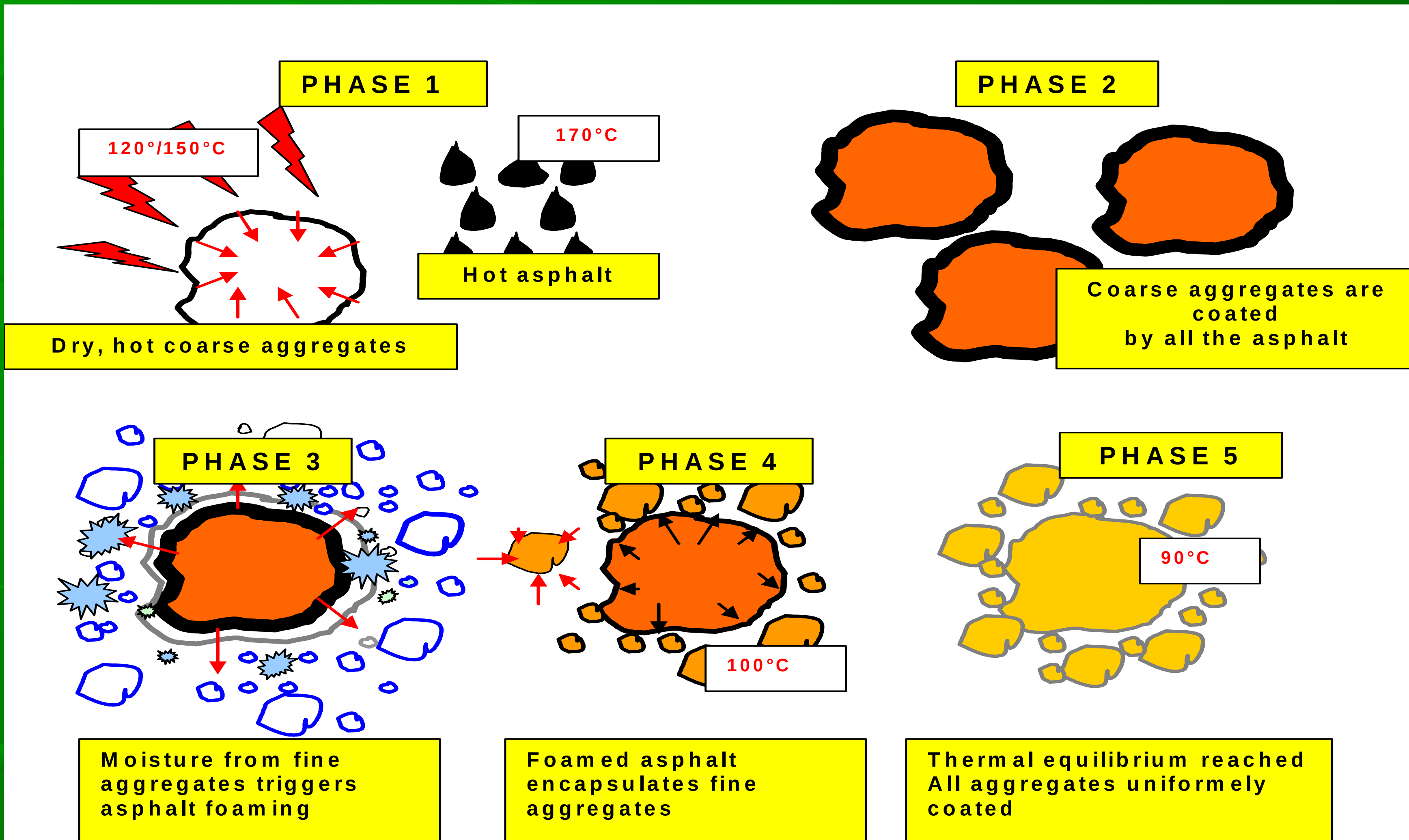
Considerations During Development of Half-Warm Coating Process

- Make the best use of bitumen state changes as a function of its temperature during contact with aggregate surfaces and water
  - In particular, the ability of foamed bitumen to coat cold elements of small dimensions
- Possibility of optimizing energy inputs during manufacturing process through the use of specific functions performed by:
  - All elements: coarse aggregate, fine aggregate, bitumen, water
  - An element deliberately conserved during manufacture: water
  - The transformation of bitumen into foamed bitumen

Functionality of Components

Table 4: Functionality of components		
Element	**Usage function**	**Manufacturing function**
Coarse aggregate	**Bearing structure**	**« Specific heat » reservoir**
Fine aggregate	**Filling of voids in bearing structure**	**Transport of water capture of heat**
bitumen	**Warm, it has the capacity to coat the coarse aggregate**	**Heat bridge between coarse aggregate and fine aggregate**
Water	**Emulsion and foam support**	**Foaming and lubricating agent, heat bridge and temperature limiter**
Foam bitumen	**Binder coating the fine elements preferentially**	**Heat insulator and "latent heat" reservoir**

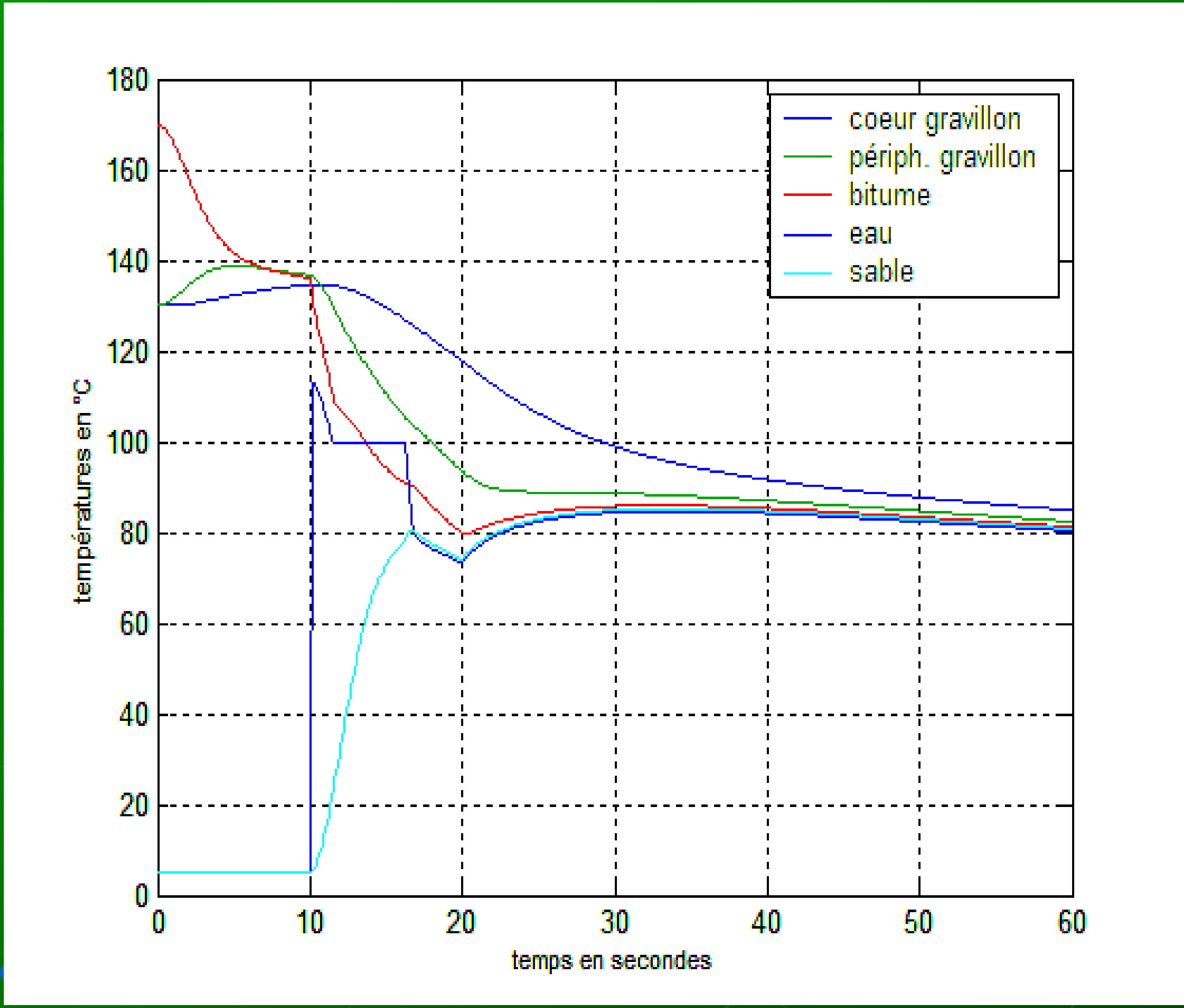
Sequential Mixing



Numerical Simulation of Coating Kinetics

- Matlab Simulink software used
  - Single-dimensional nonstationary model based on nodal methods
  - A component is regarded as a thermal node whose temperature evolves under the effect of fluxes of heat and material that it exchanges with neighboring nodes

Heat Transfer Thermogram



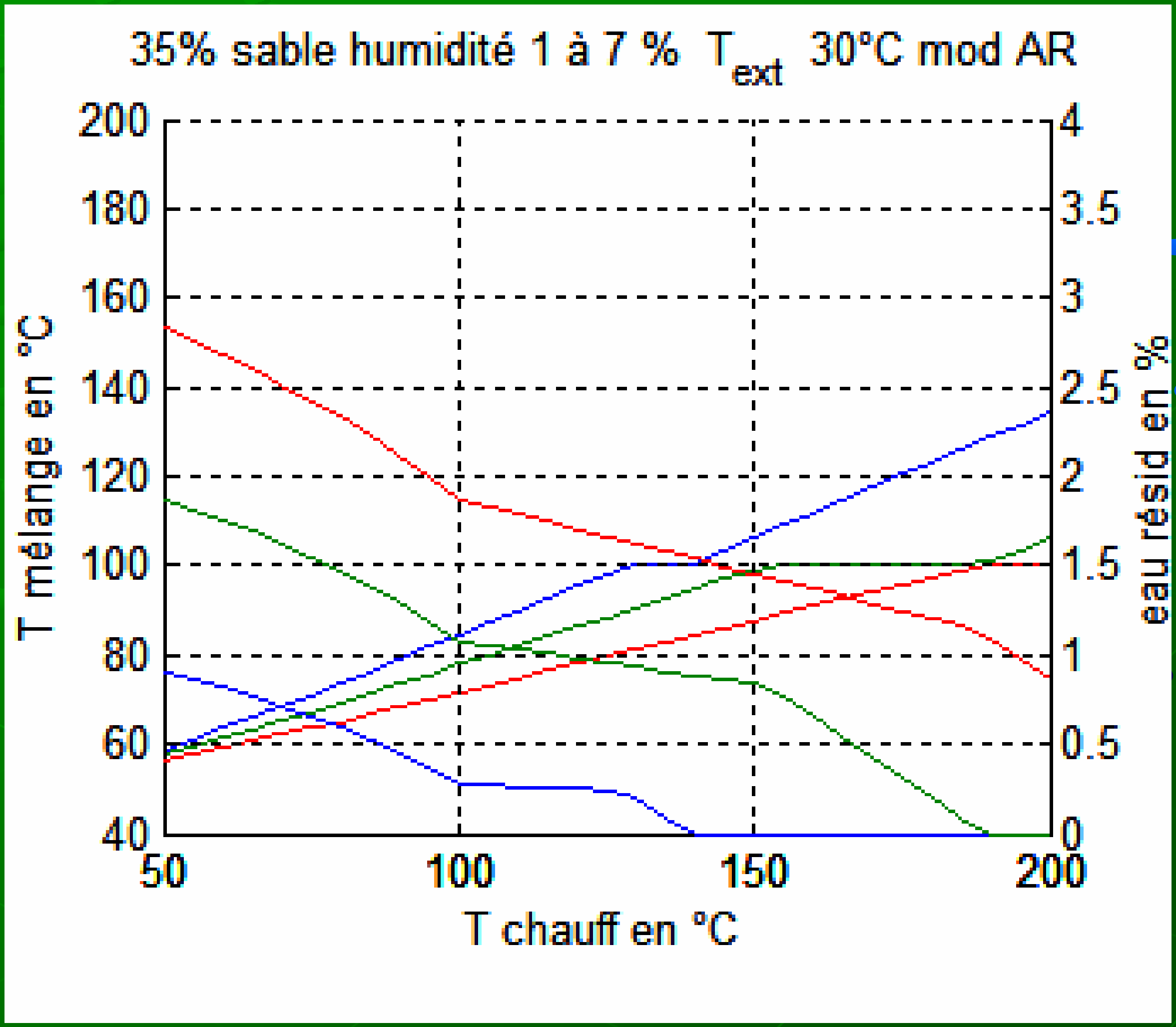
HMA Energy Consumption Based on Energy Management Model

Table 5: Comparison of heating energy required to produce the same mixture, according to HMA and WMA sequential coating, processes	Data % in mixes	Mass in kg
Table 5a : Heating energy to produce hot mix asphalt		
Initial water content of fine aggregate (sand) in %	3.0	
Water content of coarse aggregate in %	1.0	
Initial temperature of aggregate in °C	15.0	
Initial temperature of asphalt binder in °C	160.0	
Input of dry and hot aggregate (coarse aggregate, part of fine aggregate, sand and filler) in %	66.0	625.0
Input of wet aggregate in dry weight (fine aggregate, sand) in %	34.0	322.0
Asphalt binder in pph	5.3	53.0
Water remaining in hot mix in %	0.0	0.00
Eliminated coarse aggregate and sand water		15.91
Totals		1000.00
Final temperature of mix in °C	165.0	
Heating energy in KJ		161,000
Heavy fuel oil consumption not including losses in kg/t		3.98

Half-Warm Mix #6 Consumption Based on Energy Management Model

Table 5 : Comparison of heating energy required to produce the same mixture, according to HMA and WMA LEA, processes	Data % in mixes	Mass in kg
Table 5b : Heating energy to produce half-warm mix Sequential coating		
Initial water content of fine aggregate (sand)	3.0	
Water content of coarse aggregate in %	1.0	
Initial temperature of wet fine aggregate (sand) in °C	15.0	
Input temperature of coarse aggregate in °C	130.0	
Initial temperature of asphalt binder in °C	160.0	
Dry coarse aggregate in %	66.0	620.5
Fine aggregate in dry weight in %	34.0	319.7
Asphalt binder in pph	5.3	52.7
Water remaining in half warm mix in %	0.71	7.1
Eliminated coarse aggregate water		6.2
Initial water transformed into vapor in %	25.8	2.5
Totals		1000,00
Final temperature of mix in °C	90.0	
Heating energy in KJ		76,100
Heavy fuel oil consumption not including losses in kg/t		1.88

Importance of Model



Conclusions

- The method used to develop the half-warm mix shows that evaluating the energy content of an asphalt mix is essential for its environmental validation
- This thermodynamic approach enables a better understanding and control of the physical phenomena mobilized by the different warm and half-warm processes
- It offers a thermal model of process operation and allows the calculation of related energy parameters

QUESTIONS?

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